AD-A254 254

ITATION PAGE

Form Approved
OMB No. 0704-0188

ed to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, iewing the collection of information. Send comments regarding this burden estimate or any other aspect of this rden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson ffice of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
5 Nov 91

3. REPORT TYPE AND DATES COVERED
Scientific Report

2

4. TITLE AND SUBTITLE
A FIELD INVESTIGATION OF DTED SUITABILITY FOR LINE-OF-SIGHT (LOS) APPLICATIONS

5. FUNDING NUMBERS

6. AUTHOR(S)
Louis A. Fatale & Jeffrey A. Messmore

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Topographic Engineering Center
ATTN: CETEC-LO
Fort Belvoir, VA 22060-5546

8. PERFORMING ORGANIZATION REPORT NUMBER
R-158

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release;
distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Recent advance in weapon systems and combat simulators have increased the need for higher resolution data for terrain appreciation and three prediction applications. To date, the Defense Mapping Agency's (DMA) Digital Terrain Elevation Data (DTED) Level 1 database, an elevation matrix with 3 arc second or 100-meter post spacing, has been used by most military and Department of Defense(DOD) users when elevation data was required for modeling, simulations or other applications. The advent of the Tactical Terrain Data (TTD)* prototype and its corresponding DTED Level 2 cell (1 arc second spacing or 30-meter post spacing) has afforded joint service users a unique opportunity to compare the two databases in terms of their uses for relevent applications, especially line-of-sight (LOS). A major aspect of the Army's evaluation of the TTD prototype involved a comprehensive comparison of DTED Level 1 vs. Level 2 conducted by the Digital Concepts and Analysis Center (DCAC) at the United States Army Topographic Engineering Center (TEC) Fort Belvoir, VA and the prototype study area Fort Hood, TX.

14. SUBJECT TERMS
Tactical Terrain Data (TTD), line-of-sight (LOS), DTED Level 1 vs. Level 2

15. NUMBER OF PAGES
14

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	

NSN 7540-01-280-5500 Stand...

A FIELD INVESTIGATION OF DTED SUITABILITY FOR LINE-OF-SIGHT (LOS) APPLICATIONS

Louis A. Fatale
Jeffrey A. Messmore

U.S. Army Topographic Engineering Center
Ft. Belvoir, VA 22060-5546

ABSTRACT

Recent advances in weapon systems and combat simulators have increased the need for higher resolution data for terrain appreciation and threat prediction applications. To date, the Defense Mapping Agency's (DMA) Digital Terrain Elevation Data (DTED) Level 1 database, an elevation matrix with 3 arc second or 100-meter post spacing, has been used by most military and Department of Defense (DOD) users when elevation data was required for modeling, simulations or other applications. The advent of the Tactical Terrain Data (TTD)* prototype and its corresponding DTED Level 2 cell (1 arc second spacing or 30-meter post spacing) has afforded joint service users a unique opportunity to compare the two databases in terms of their uses for relevant applications, especially line-of-sight (LOS). A major aspect of the Army's evaluation of the TTD prototype involved a comprehensive comparison of DTED Level 1 vs. Level 2 conducted by the Digital Concepts and Analysis Center (DCAC) at the United States Army Topographic Engineering Center (TEC), Fort Belvoir, VA and the prototype study area, Fort Hood, TX. The accuracy of masked and unmasked areas within LOS prediction plots (using DTED Level 1 and Level 2 as input) was compared to actual LOS plots compiled in the field for selected origin points.

This paper will present an overview of the unique procedures employed to compile LOS in the field. It will also provide a review of the comprehensive analysis performed on the DTED generated LOS and the field LOS. The findings of the field investigations will be used to ascertain whether currently available DTED represents the real terrain adequately for joint services applications.

---

* Current TTD is a prototype digital terrain data set containing vector based features and attributes and a high resolution elevation matrix. Subsequent TTD will be produced by DMA (circa 1997) to satisfy future joint services requirements.

INTRODUCTION

Prediction of line-of-sight (LOS) conditions has always been an essential aspect of the battlefield. Knowledge of the surrounding terrain and its corresponding elevation has even more implications today in the modern Army. Recent advances in weapon systems and combat simulators have increased the need for higher resolution data for terrain appreciation and threat prediction applications. To date, DMA's DTED Level 1 database, an elevation matrix with 3 arc second or 100-meter post spacing, has been used by most military and DOD users when elevation data was required for modeling, simulations or other applications. The advent of the TTD prototype and its corresponding DTED Level 2 cell (1 arc second spacing or 30-meter post spacing) has afforded joint service users a unique opportunity to compare the two databases in terms of their uses for relevant applications, especially LOS. In fact, a major aspect of the Army's evaluation of the TTD prototype involved a comprehensive comparison of DTED Level 1 vs. Level 2 conducted by DCAC. The following discussion outlines this effort which was accomplished through a series of field trips to the prototype study area at Fort Hood, TX.

PURPOSE

The purpose of this study was to compare the accuracy of masked and unmasked areas within LOS prediction plots generated from DTED Level 1 and Level 2 to plots compiled in the field. These evaluation results were, in part, used to ascertain whether the elevation information contained in TTD represented the real terrain adequately for joint services applications.

METHODOLOGY

DCAC initiated its field work with a site visit to the TTD prototype area during March 1989. A number of prospective LOS origin points were identified at this time; corresponding geographic coordinates were determined using a DMA 1:50,000 scale topographic line map (TLM). Four points (A-D) were eventually chosen for analysis and stakes placed in the ground to mark their locations. DCAC's engineering support contractor produced 1:24,000 scale DTED Level 1 and Level 2 prediction plots (on transparent media) for each point using the origin coordinates as ascertained in the field. These coordinates were subsequently verified as sufficiently accurate (mean error 45 meters) for the purposes of this study through differential positioning methodology with a GPS receiver. Finally, DCAC personnel revisited the origin points to compile field LOS plots

which would later be compared to the DTED Levels 1 and 2 prediction plots.

PROCEDURE

The field LOS plots were acquired via a four step process:

1) For initial orientation, the DTED prediction plots were registered to a 1:24,000 USGS TLM on which each specific origin point had been carefully mapped. A visual inspection of the site was then conducted whereby all obvious errors in the prediction plots were annotated. This procedure helped to clarify the plots for later analysis.

2) The field team split into two crews.

3) The first crew set up a theodolite at the origin point to obtain lines of azimuth. The azimuths were shot at approximately 20 degree intervals, with intermediate rays focusing on special terrain conditions, in a 360-degree sweep around the site.

4) The second crew traveled along each azimuth remaining true to the heading via directional instructions radioed to them by the first crew. Whenever sight was lost or gained along each azimuth in relation to the origin point, a distance measurement was taken using laser distance measuring equipment. LOS lost because of intervening vegetation was noted and differentiated from LOS lost because of terrain in order to obtain the most precise representation of reality. In addition, conditions existed at Fort Hood where vegetation did not actually obstruct LOS, but prevented clear view of the underlying ground surface, such as on a tree-covered ridge. In this case, the character of both LOS conditions was recorded; one representing clear LOS from the origin point to the lower edge of the tree line, and one representing LOS from the tree line to the top of the ridge indicating that the ground surface was not visible but that LOS extended to the ridge line. This recording procedure continued on each azimuth until sight was permanently lost.

In addition to the LOS measurements, photographs were taken and landmarks noted in a 360-degree panorama around all four points. This information, in conjunction with the annotated prediction plots (see step 1 above), proved valuable in terms of orientation during subsequent plotting of the data.

PLOTTING THE DATA

The raw data collected in the field were plotted onto 1:4800 scale aerial photographs obtained at Fort Hood and covering the study area. These photographs were vital in assuring correct initial alignment and accuracy of the azimuths. Once this was accomplished, the field fans (those areas determined to be visible from each of the four field origin points, including any masked regions contained within them) were reduced to 1:24,000 scale, then overlayed and compared to the DTED-generated LOS prediction plots. LOS or the lack of it within the field fan is depicted in three ways on the field-generated plots. A solid line indicates clear sight, a dashed line indicates the presence of vegetation on otherwise visible ground, and the absence of a line indicates sight blocked by terrain or lost at the distant horizon.

ANALYSIS

LOS analyses for this study were conducted based on 2 areal configurations: 1) the total prediction area and 2) the field fan. The total prediction area roughly equals the 10-by-10 minute prototype study area while the field fan is a variably sized area dependent upon LOS conditions around a given observation point.

Tables 1-8 summarize results of the comparison of DTED predictions versus field results for each of the four LOS origin points. The tables present results of prediction confidence for the total prediction area as well as within the field fan only. These aspects of the DTED prediction must be considered in tandem to achieve a complete understanding of the field analyses. Unmasked and masked areas were identified and analyzed since errors in either one may have serious implications on joint services applications.

Coincidence Within the Field Fan

The first comparison analysis undertaken between the DTED prediction plots and the field data was the determination of coincidence within the field fan (see Tables 2, 4, 6, & 8). In this analysis, the rest of the prediction area was ignored and only coinciding masked or unmasked areas within the field fan were measured to establish a percentage of coincidence. Next, in order to determine a measure of integrity for the combined masked and unmasked areas, the percent coincidence values were assigned a weighting, based on percentage of areal coverage within the fan, and finally averaged. The resultant weighted average coincidence percentage is one way to assess the accuracy of the DTED prediction plots

Table 1
Summary of Line of Sight Prediction vs. Field Results
(Total Prediction Area)

Line of Sight Point A

Line of Sight Condition	Prediction (m^2)	Field Results (m^2)	Prediction Error -=Under +=Over (m^2)
DTED 1			
Unmasked	31.3×10^6	$.9 \times 10^6$	$+30.4 \times 10^6$
Masked	205.8×10^6	236.2×10^6	-30.4×10^6
Total Prediction Area	237.1×10^6	237.1×10^6	N/A
DTED 2			
Unmasked	4.2×10^6	$.9 \times 10^6$	$+3.3 \times 10^6$
Masked	232.9×10^6	236.2×10^6	-3.3×10^6
Total Prediction Area	237.1×10^6	237.1×10^6	N/A

Table 2
Summary of Line of Sight Prediction vs. Field Results
(Coincidence within the Field Fan)

Line of Sight Point A

Line of Sight Condition	Prediction (m^2)	Field Results (m^2)	Coincidence (%)	Weighted Average Coincidence (%)
DTED 1				
Unmasked	0.84×10^6	0.88×10^6	95	95
Masked	0.00×10^6	0.00×10^6	100	
DTED 2				
Unmasked	0.63×10^6	0.88×10^6	72	72
Masked	0.00×10^6	0.00×10^6	100	

Table 3
Summary of Line of Sight Prediction vs. Field Results
(Total Prediction Area)

Line of Sight Point B

Line of Sight Condition	Prediction (m^2)	Field Results (m^2)	Prediction Error - = Under + = Over (m^2)
	DTED 1		
Unmasked	18.3×10^6	$.8 \times 10^6$	$+17.5 \times 10^6$
Masked	196.9×10^6	214.4×10^6	-17.5×10^6
Total Prediction Area	215.2×10^6	215.2×10^6	N/A
	DTED 2		
Unmasked	3.2×10^6	$.8 \times 10^6$	$+2.4 \times 10^6$
Masked	212.0×10^6	214.4×10^6	-2.4×10^6
Total Prediction Area	215.2×10^6	215.2×10^6	N/A

Table 4
Summary of Line of Sight Prediction vs. Field Results
(Coincidence within the Field Fan)

Line of Sight Point B

Line of Sight Condition	Prediction (m^2)	Field Results (m^2)	Coincidence (%)	Weighted Average Coincidence (%)
	DTED 1			
Unmasked	0.76×10^6	0.84×10^6	90	85
Masked	0.20×10^6	0.29×10^6	69	
	DTED 2			
Unmasked	0.84×10^6	0.84×10^6	100	74
Masked	0.00×10^6	0.29×10^6	0	

Table 5
Summary of Line of Sight Prediction vs. Field Results
(Total Prediction Area)

Line of Sight Point C

Line of Sight Condition	Prediction (m^2)	Field Results (m^2)	Prediction Error - = Under + = Over (m^2)
	DTED 1		
Unmasked	19.0×10^6	4.2×10^6	$+14.8 \times 10^6$
Masked	196.2×10^6	211.0×10^6	-14.8×10^6
Total Prediction Area	215.2×10^6	215.2×10^6	N/A
	DTED 2		
Unmasked	27.3×10^6	4.2×10^6	$+23.1 \times 10^6$
Masked	187.9×10^6	211.0×10^6	-23.1×10^6
Total Prediction Area	215.2×10^6	215.2×10^6	N/A

Table 6
Summary of Line of Sight Prediction vs. Field Results
(Coincidence within the Field Fan)

Line of Sight Point C

Line of Sight Condition	Prediction (m^2)	Field Results (m^2)	Coincidence (%)	Weighted Average Coincidence (%)
	DTED 1			
Unmasked	1.12×10^6	4.23×10^6	26	54
Masked	3.05×10^6	3.47×10^6	88	
	DTED 2			
Unmasked	3.47×10^6	4.23×10^6	82	68
Masked	1.72×10^6	3.47×10^6	50	

Table 7
Summary of Line of Sight Prediction vs. Field Results
(Total Prediction Area)

Line of Sight Point D

Line of Sight Condition	Prediction (m^2)	Field Results (m^2)	Prediction Error -=Under += Over (m^2)
DTED 1			
Unmasked	17.7 $x10^6$	2.0 $x10^6$	+15.7 $x10^6$
Masked	197.5 $x10^6$	213.2 $x10^6$	-15.7 $x10^6$
Total Prediction Area	215.2 x 10^6	215.2 x 10^6	N/A
DTED 2			
Unmasked	3.1 $x10^6$	2.0 $x10^6$	+1.1 $x10^6$
Masked	212.1 $x10^6$	213.2 $x10^6$	-1.1 $x10^6$
Total Prediction Area	215.2 x 10^6	215.2 x 10^6	N/A

Table 8
Summary of Line of Sight Prediction vs. Field Results
(Coincidence within the Field Fan)

Line of Sight Point D

Line of Sight Condition	Prediction (m^2)	Field Results (m^2)	Coincidence (%)	Weighted Average Coincidence (%)
DTED 1				
Unmasked	1.34 x 10^6	2.00 x 10^6	67	55
Masked	0.09 x 10^6	0.60 x 10^6	15	
DTED 2				
Unmasked	1.70 x 10^6	2.00 x 10^6	85	72
Masked	0.17 x 10^6	0.60 x 10^6	28	

compared to the real world -- but only within the field fan. Conclusions cannot be fully drawn from this analysis until the total prediction area is scrutinized.

Total Prediction Area Evaluation

In this analysis, the prediction area (approximately 10-by-10 minute area) around each origin point, including the field fan, was evaluated (see Tables 1, 3, 5, & 7). All unmasked and masked areas not matching the field results were considered in error. These areas of error were tabulated (in square meters) to determine the total under or over prediction error within the DTED LOS prediction plots for each point. It is obvious that the value of a database for LOS support increases as over and under prediction errors are reduced. Therefore, this analysis is important in that it provides a measure of DTED integrity over a large viewing area.

Graphic Comparison

In order to graphically portray the DTED visibility prediction versus ground truth for each observation point, Figures 1 through 4 were prepared. These figures show the spatial distribution of both correct and incorrect predictions about each point.

RESULTS SUMMARY

The main concern that the DCAC field team attempted to address during the LOS investigations was that of determining which dataset, DTED Level 1 or DTED Level 2, best represents the real world in terms of supporting future Army applications. The following section will attempt to clarify the performance of DTED Level 1 and Level 2 by integrating the results of the field fan and total prediction area analyses for each point.

Prediction Coincidence Within the Field Fan vs. the Total Prediction Area

In the field fan analyses, DTED Level 1 was the better predictor for points A (95 percent vs. 72 percent) and B (85 percent vs. 74 percent) as shown in Tables 2 and 4. However, much of the coincidence in the Level 1 data for points A and B is mitigated by the extremely high prediction errors that occur in the total prediction area around these points. The DTED Level 1 prediction plots overestimated unmasked areas by over 30 million square meters for point A and over 17 million square meters for point B, two of the worst predictions in the entire study. As noted, the DTED Level 2 prediction plots for points A and B were slightly worse predictors in terms of coincidence within the field fan; however,

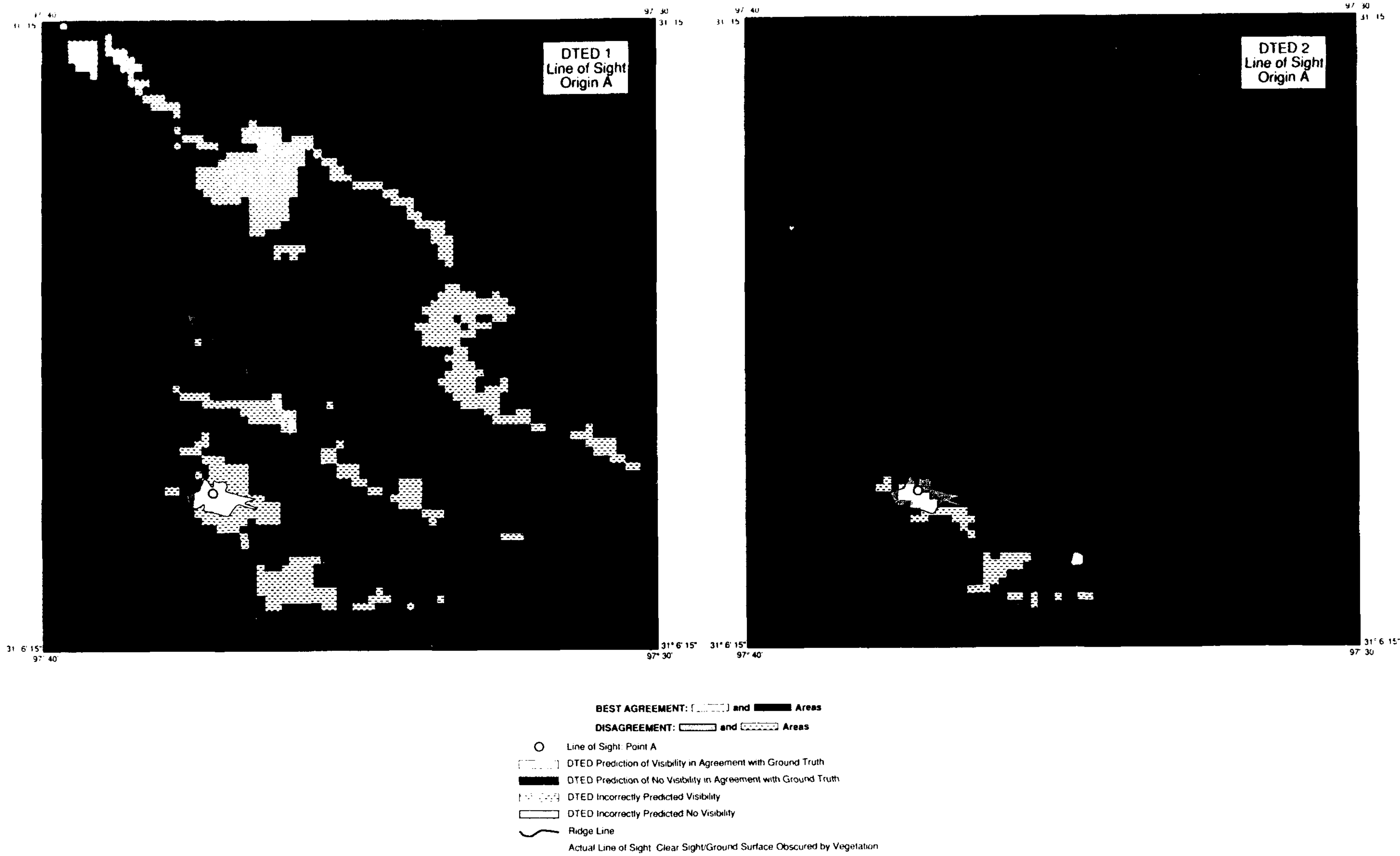


Figure 1 Predicted Visibility DTED 1 and 2 vs Ground Truth

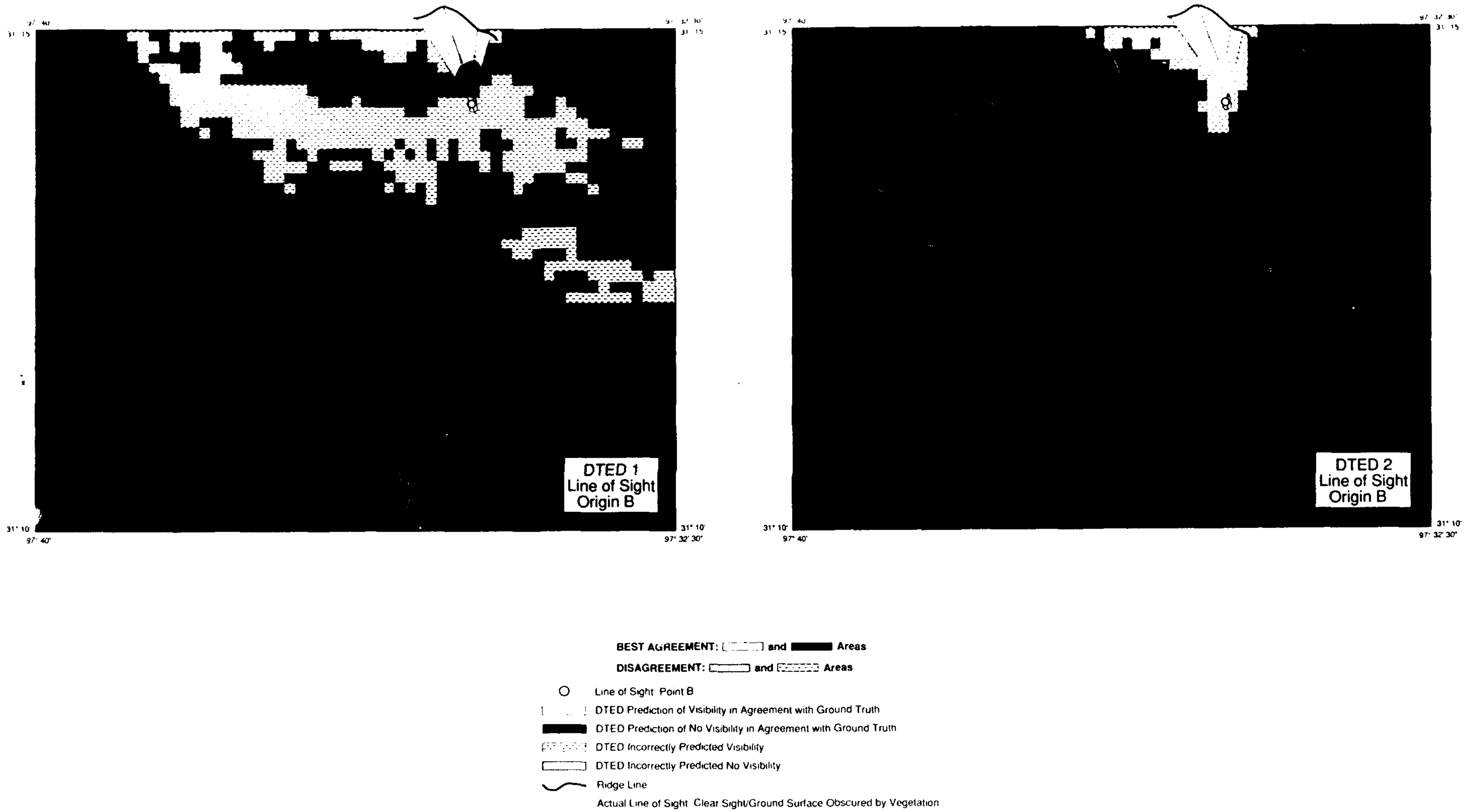


Figure 2. Predicted Visibility DTED 1 and DTED 2 vs Ground Truth

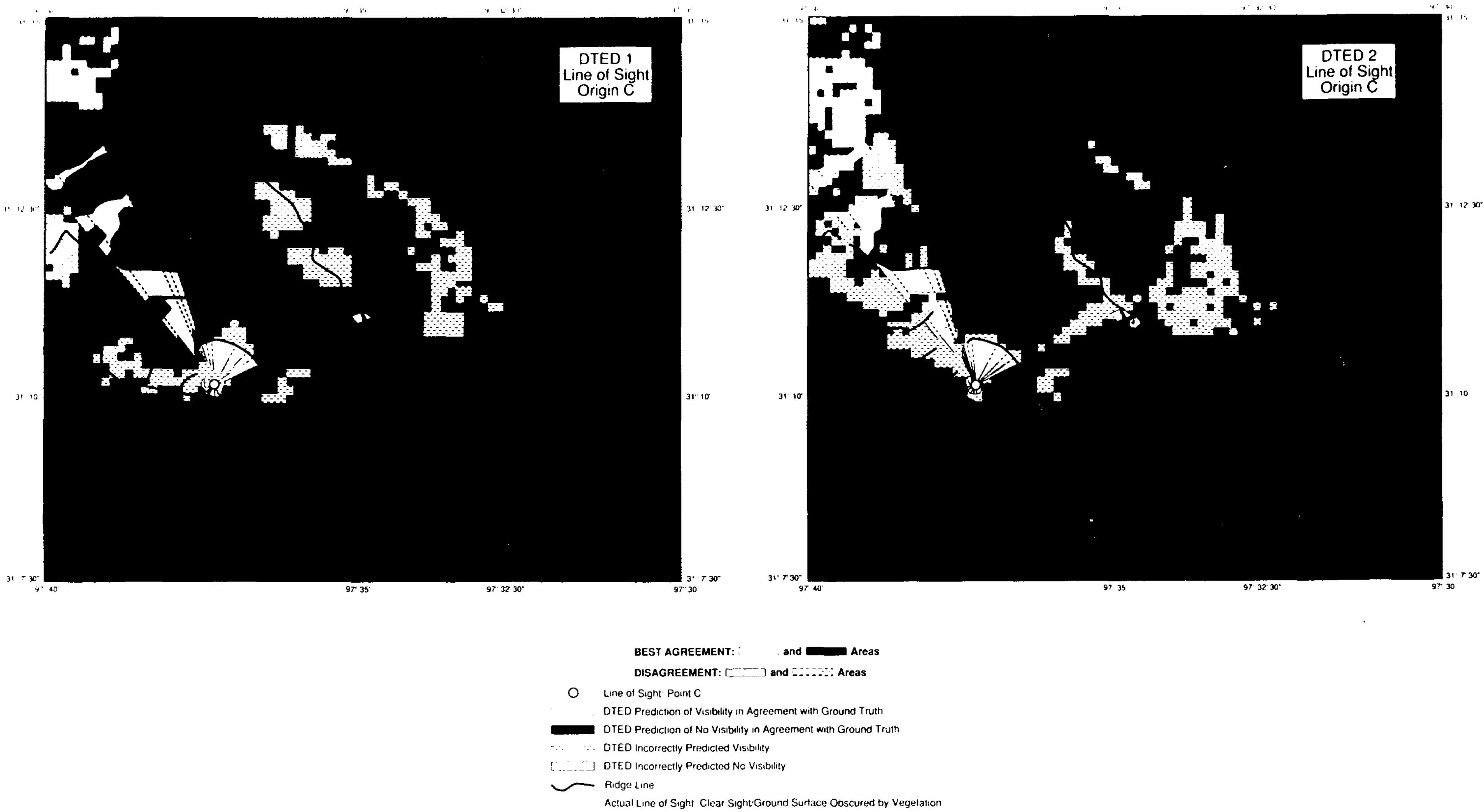
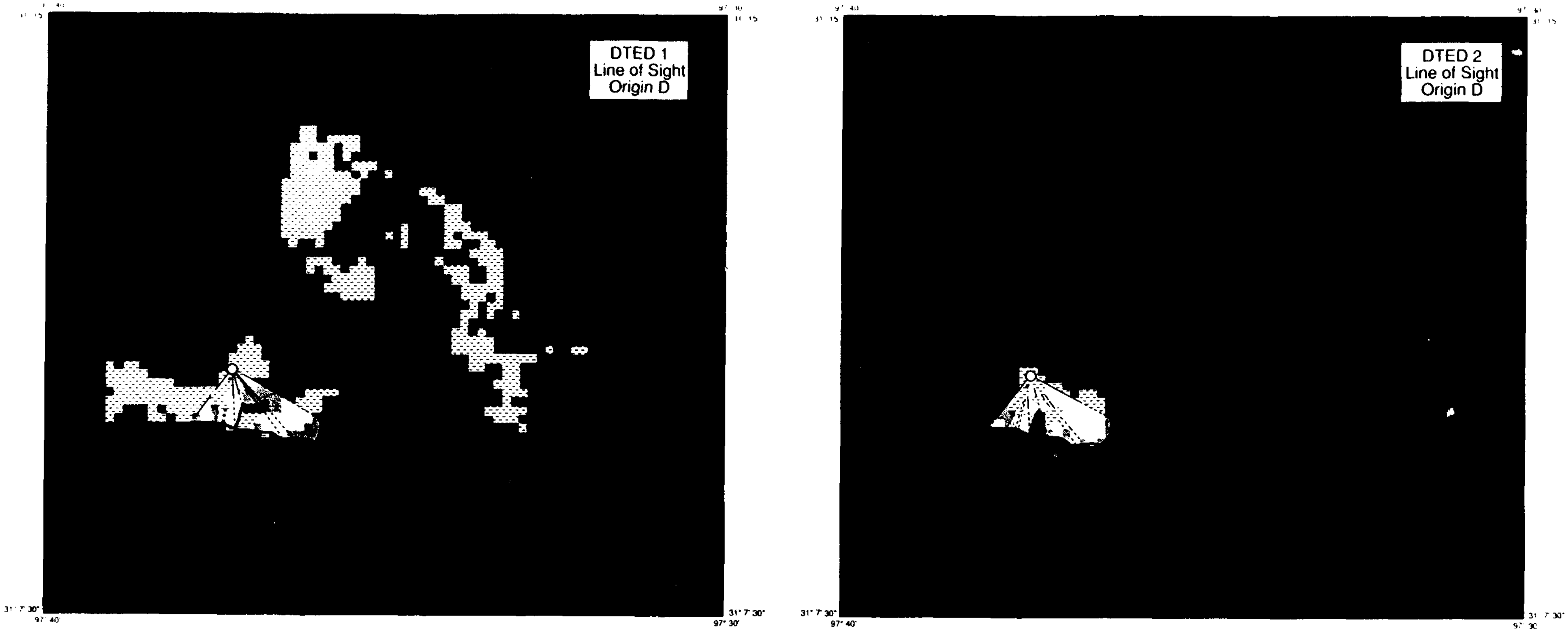


Figure 3. Predicted Visibility DTED 1 and 2 vs Ground Truth



BEST AGREEMENT: and **Areas**

DISAGREEMENT: and **Areas**

Line of Sight: Point D

DTED Prediction of Visibility in Agreement with Ground Truth

DTED Prediction of No Visibility in Agreement with Ground Truth

DTED Incorrectly Predicted Visibility

DTED Incorrectly Predicted No Visibility

Ridge Line

Actual Line of Sight: Clear Sight/Ground Surface Obscured by Vegetation

Figure 4 Predicted Visibility DTED 1 and 2 vs Ground Truth

their performance over the corresponding total prediction areas was excellent. Prediction errors measured only 3.3 million and 2.4 million square meters for points A and B, two of the three best predictions in the study (see Tables 1 and 3).

In the field fan analyses for points C and D, DTED Level 2 was the better predictor (68 percent vs. 54 percent and 72 percent vs. 55 percent) as shown in Tables 6 and 8. The DTED comparisons for the total prediction area around point D are easily discernable. The DTED Level 2 prediction error measured only 1.1 million square meters. This was the lowest error measured in the study and was in stark contrast to the 15.7 million square meter prediction error on the DTED Level 1 plot (see Table 7). Results for point C, however, were not as clear. Although, as stated above, the DTED Level 2 plot had a slightly better coincidence within the field fan, it predicted poorly in the total prediction area with a prediction error of 23.1 million square meters versus 14.8 million square meters for Level 1 (see Table 5).

CONCLUSIONS

Several conclusions are evident in light of the results above:

- Both coincidence within the field fan and accuracy of prediction for the total prediction area must be evaluated when attempting to determine a preference between DTED Level 1 and DTED Level 2 for the generation of LOS prediction plots (see Figures 1-4). The accuracy of a prediction plot for the total prediction area around an origin point is equally as important as its coincidence within the corresponding field fan. High LOS coincidence near an origin point can be mitigated by gross prediction errors in surrounding areas. This is precisely the situation found at points A and B. The gross misprediction of the DTED Level 1 prediction plots in the total prediction area around points A and B more than negates the high coincidences (84 percent and 95 percent) evident within the field fan. In contrast, the correspondence of DTED Level 2 prediction plots in the total prediction areas around points A and B was excellent (see Tables 1 and 3) with field fan coincidences still over 70 percent. The superiority of DTED Level 2 was also evident at point D where the total prediction area was almost perfectly predicted (see Table 7) and a 72 percent weighted average coincidence value was recorded within the field fan. For these reasons, DTED Level 2 data must be considered the better overall predictor for LOS at points A, B, and D, especially D.

- Neither DTED Level 1 nor DTED Level 2 performed well at point C. Within the field fan, the DTED Level 2 prediction plot had a higher coincidence (68 percent) than the Level 1 plot (54 percent) but both had unacceptable prediction errors in the total prediction area. The DTED Level 2 plot overpredicted LOS by 23 million square meters while the Level 1 plot overpredicted LOS by 14 million square meters. Both plots exhibited some areas of reasonable correspondence, but neither prediction was considered consistent enough to be useful. Complex terrain conditions around point C seem to have taxed the limits of DTED accuracy and/or resolution, thus limiting the prediction capabilities of both data sets. In any event, the difficulty in predicting LOS around point C clearly exemplifies the need for caution when using digital elevation data for LOS predictions. Indeed, all digital topographic data (DTD) must be intelligently evaluated in terms of accuracy and resolution limitations before being used for simulation or battlefield applications.

- Although results at point C were inconclusive, LOS around the three remaining points was clearly better represented by the prediction plots generated from DTED Level 2. <u>DTED Level 2 is a more consistent predictor of LOS than DTED Level 1</u> and its use and importance will increase as joint services applications become more sophisticated.